Conveyance Study B –Upper Stony Creek

Introduction

This study focused on an initial analysis of alternatives to divert winter flows from upper Stony Creek to the proposed Sites or Colusa Reservoirs. This work was conducted as part of the North of Delta Offstream Storage Investigation. A storable source of water could be diverted at either Stony Gorge or East Park Reservoir. Figures 13 and 14 show the project area. The study summarized in *Hydrology and Water Supply for Offstream Reservoirs*, November 1999, determined that approximately 70,000 acre-feet per year is divertible from Stony Gorge Reservoir and up to 35,000 acre-feet per year is divertible from East Park Reservoir without infringing on existing water rights or reservoir storage at the start of the irrigation season in April. This report contains the results of a reconnaissance study to determine alternative conveyance routes, quantities of earthwork and placed concrete, and costs of appurtenances, based on surface geology mapping. Subsurface geology was not investigated by drilling, and the geology used here is interpreted based on subsurface geology at Sites and Colusa Dam sites.

Summary of Results

The costs estimated in this report are intended to be used for comparison of alternatives and not for actual construction costs, which would require a higher level of study to estimate accurately. The total base cost, excluding contingencies, engineering, regulatory costs, operation and maintenance, capital repayment, energy costs, or interest during construction, would range from $145 million to $220 million for the Stony Gorge to Sites conveyance alternative. Diversion sizes range from 1,000 cubic feet per second to 2,000 cfs. The base cost of the East Park to Sites alternative would range from $49 million to $74 million for capacities from 800 cfs to 1,200 cfs.

Final costs, including all the above excluded costs, would be about double the base costs listed above. Tables 2, 3, and 4 contain the cost estimates that are the essence of this report, showing the comparative base costs of investigated tunnel alternatives, canal alternatives, and combined conveyance systems, respectively.

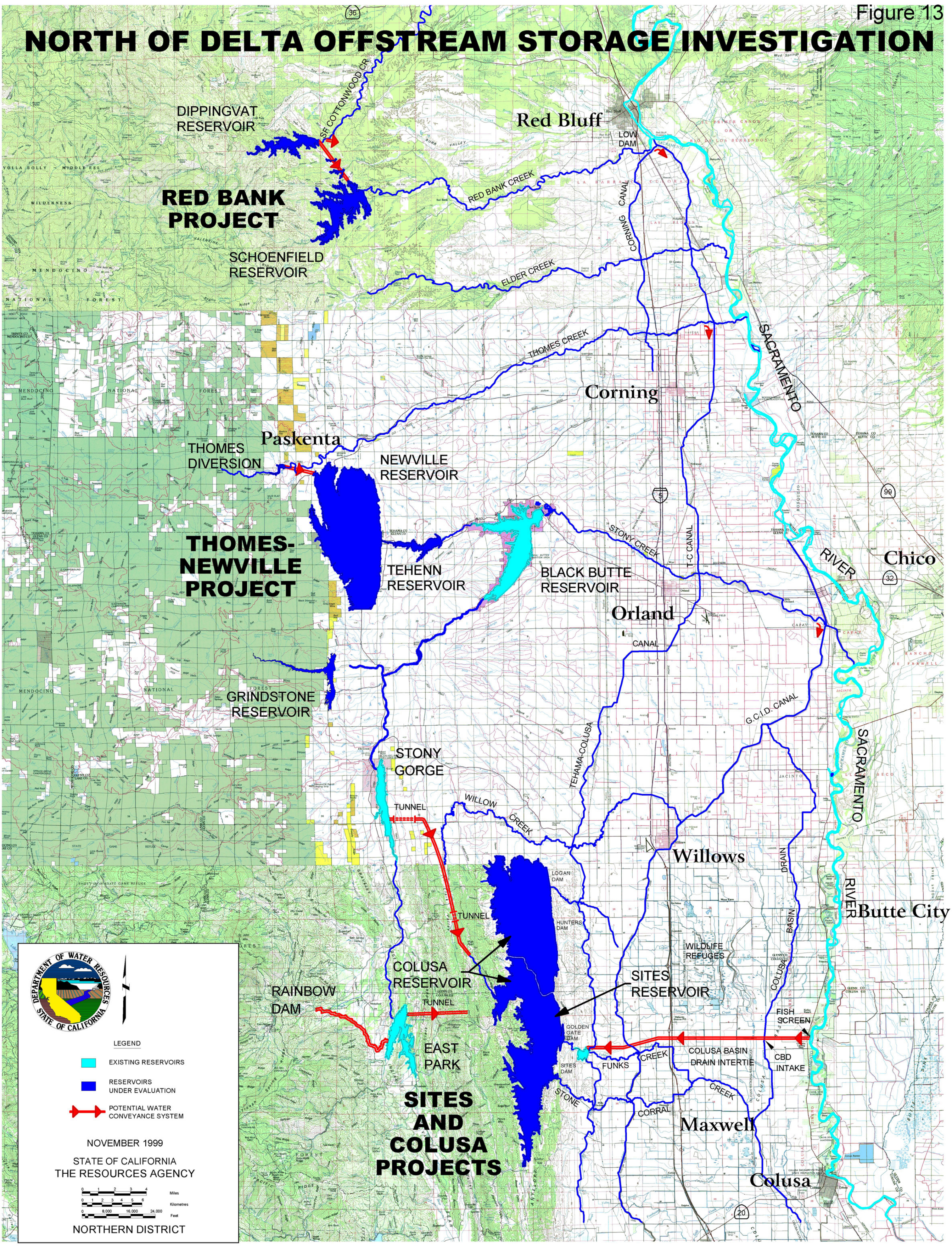
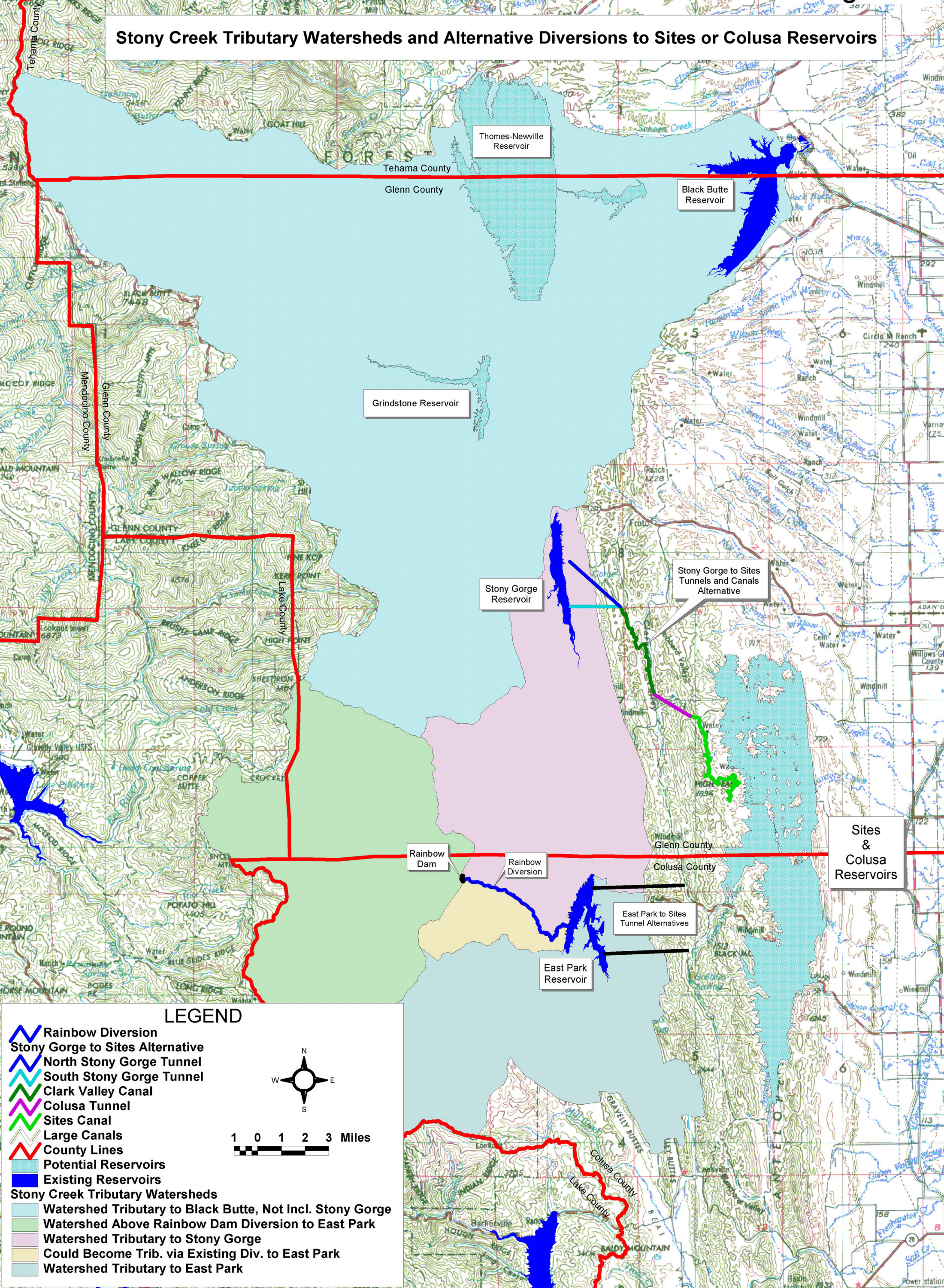


Figure 13
NORTH OF DELTA OFFSTREAM STORAGE INVESTIGATION
DIPPINGVAT RESERVOIR
SF COTTONWOOD CR
RED BANK PROJECT
SCHOENFIELD RESERVOIR
Red Bluff
LOW DAM
RED BANK CREEK
CORNING CANAL
ELDER CREEK
THOMES CREEK
SACRAMENTO
Corning
Paskenta
THOMES DIVERSION
NEWVILLE RESERVOIR
THOMES-NEWVILLE PROJECT
TEHENN RESERVOIR
BLACK BUTTE RESERVOIR
STONY CREEK
T.C CANAL
RIVER
Chico
Orland
CANAL
GRINDSTONE RESERVOIR
G.C.I.D. CANAL
STONY GORGE
TEHAMA-COLUSA
SACRAMENTO
TUNNEL
WILLOW CREEK
Willows
DRAIN
RIVER
Butte City
TUNNEL
LOGAN DAM
HUNTERS DAM
BASIN
WILDLIFE REFUGES
COLUSA RESERVOIR
SITES RESERVOIR
COLUSA
RAINBOW DAM
TUNNEL
FISH SCREEN
EAST PARK
GOLDEN GATE DAM
SITES DAM
FUNKS
CREEK
COLUSA BASIN DRAIN INTERTIE
CBD INTAKE
STONE
CORRAL
CREEK
SITES AND COLUSA PROJECTS
Maxwell
Colusa
DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
LEGEND
EXISTING RESERVOIRS
RESERVOIRS UNDER EVALUATION
POTENTIAL WATER CONVEYANCE SYSTEM
NOVEMBER 1999
STATE OF CALIFORNIA
THE RESOURCES AGENCY
NORTHERN DISTRICT

Figure 14



Stony Creek Tributary Watersheds and Alternative Diversions to Sites or Colusa Reservoirs
Thomes-Newville Reservoir
Tehama County
Glenn County
Black Butte Reservoir
Grindstone Reservoir
Mendocino County
Glenn County
Lake County
Stony Gorge Reservoir
Stony Gorge to Sites Tunnels and Canals Alternative
Sites & Colusa Reservoirs
Glenn County
Colusa County
Rainbow Dam
Rainbow Diversion
East Park to Sites Tunnel Alternatives
East Park Reservoir
Colusa County
Lake County
LEGEND
Rainbow Diversion
Stony Gorge to Sites Alternative
North Stony Gorge Tunnel
South Stony Gorge Tunnel
Clark Valley Canal
Colusa Tunnel
Sites Canal
Large Canals
County Lines
Potential Reservoirs
Existing Reservoirs
Stony Creek Tributary Watersheds
Watershed Tributary to Black Butte, Not Incl. Stony Gorge
Watershed Above Rainbow Dam Diversion to East Park
Watershed Tributary to Stony Gorge
Could Become Trib. via Existing Div. to East Park
Watershed Tributary to East Park
N
W
E
S
1 0 1 2 3 Miles

Project Description

Stony Gorge Reservoir is in Glenn County about 17 miles west of Willows, and is mapped on the Elk Creek 7.5' USGS Quadrangle. East Park Reservoir is in Colusa County about 17 miles northwest of Maxwell, and is mapped on the Gilmore Peak and Lodoga 7.5' USGS Quadrangles. East Park Reservoir is on Little Stony Creek, tributary to Stony Creek, but receives additional flows from upper Stony Creek through a 7.2 mile diversion canal. Figures 15 and 16 show these reservoirs and the diversion alternatives in detail.

Both reservoirs were constructed by USBR, and provide agricultural water for the Orland Unit Water Users Association, which now operates them during the irrigation season. The Orland Unit WUA provides water to 13,000 shareholders irrigating 20,000 acres. However, the Orland Unit WUA only diverts water from April through October, so excess winter flows above what is required to fill Stony Gorge and East Park Reservoirs from November through March are potentially available for diversion to offstream storage projects. For detailed hydrology of the Stony Creek and analysis of divertible flows from the reservoirs, refer to ND report Hydrology and Water Supply for Offstream Reservoirs, November 1999.

The 17 to 18 mile conveyance from Stony Gorge Reservoir to the proposed Sites Reservoir would be composed of an 11,000 to 15,000 foot Stony Gorge Tunnel, a 27,000 foot Clark Valley Canal, a 9,200 foot Colusa Tunnel, and a 44,000 foot Sites Canal. Design flows of 1,000, 1,500, and 2,000 cubic feet per second were considered. The maximum water surface elevation of the reservoir is 843 feet, but the operating maximum during the winter is 831 feet. Therefore, the bottom of the entrance to the tunnel (the invert) would have to be below this elevation by at least one tunnel diameter. Based on the topography of the reservoir, a starting tunnel invert of about 800 feet would be about the minimum feasible elevation.

The tunnels and canals would convey water from an invert elevation of 800 feet at Stony Gorge Reservoir, to 720 feet at the end of the Sites Canal. This drop of 80 feet over 17 to 18 miles would require the tunnels and canals to be fairly large compared to East Park alternatives, where a greater elevation drop is possible.

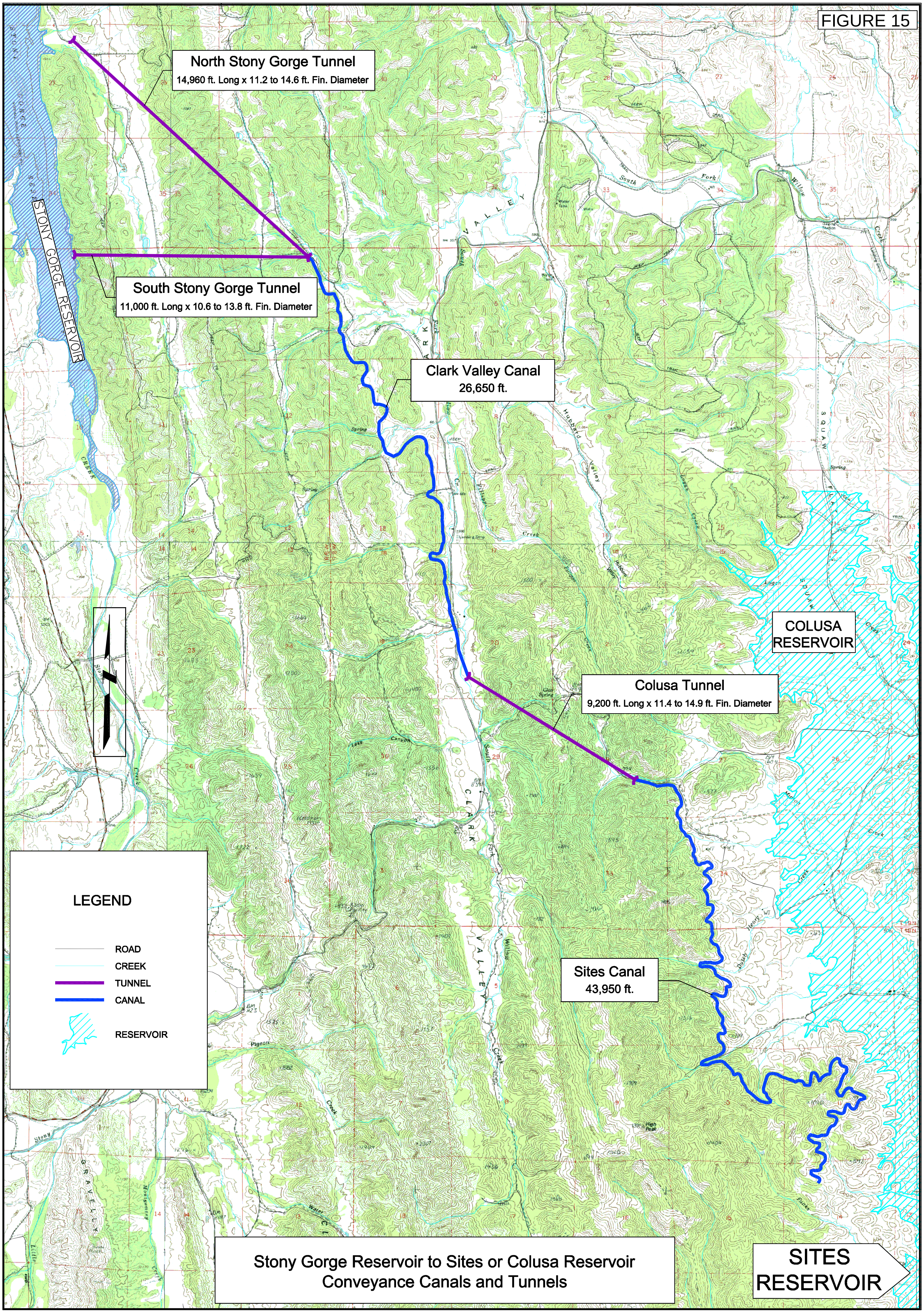
Two alternatives were considered for the alignment of the Stony Gorge Tunnel, one at the shortest possible distance and one downstream that would reduce the amount of sediment diverted. The second northern alternative would cost over 50 percent more to build but the additional cost might be offset by reduced operation and maintenance during the life of the project. Further study is needed to determine which alignment is most economical.

The entrance elevation for the Stony Gorge Tunnel was set at 800 feet, which is the lowest contour on a USGS map that extends more than halfway up into the reservoir. This was chosen as a practical limit for the elevation, without having to do large excavation within the reservoir itself and risk consequent sedimentation of the entrance. The Stony Gorge Tunnel exit invert elevation was set at the toe of the ridge to achieve a short tunnel length and a steep slope. The Colusa Tunnel entrance elevation was controlled by the lowest elevation in Clark

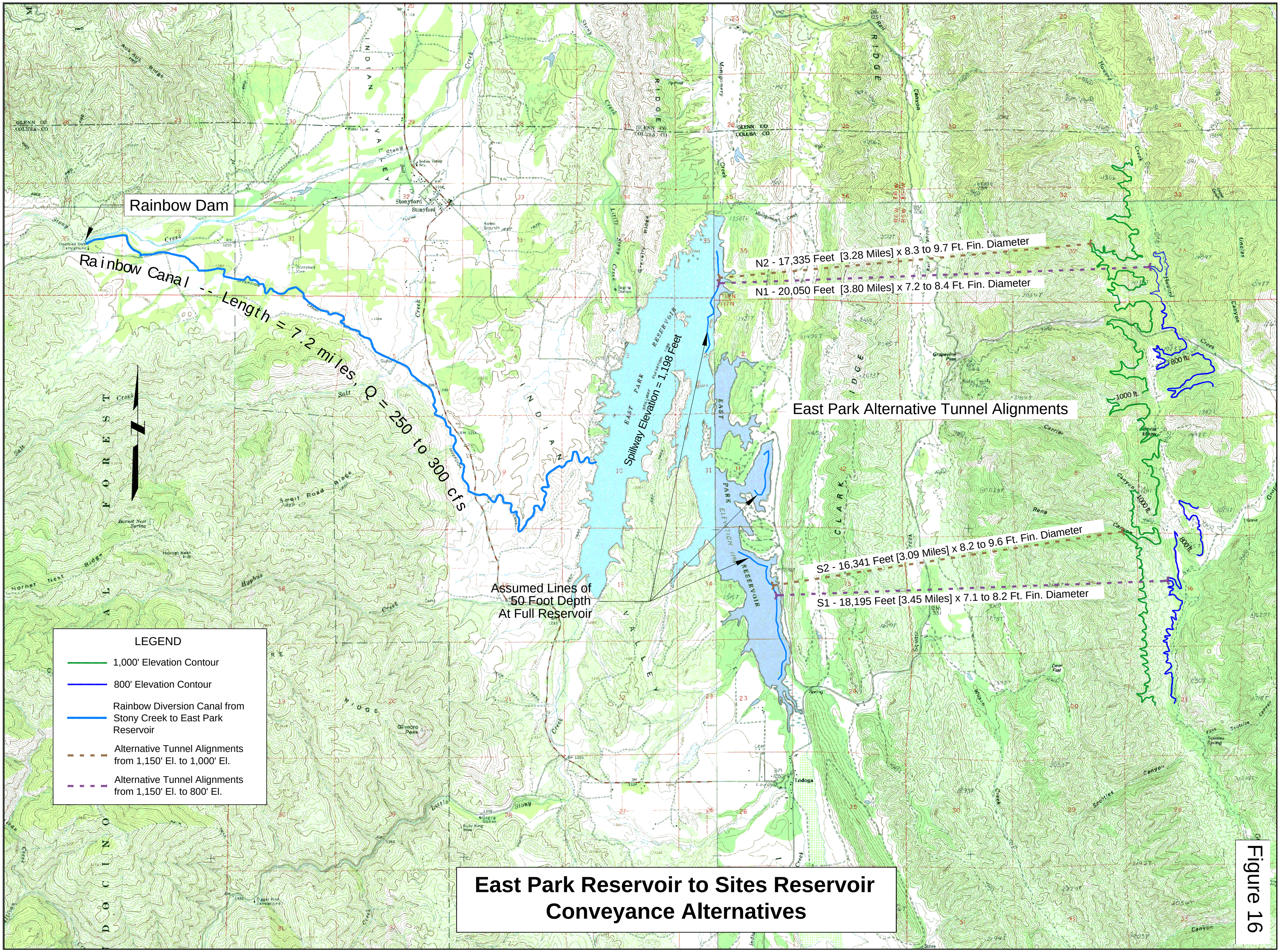
Valley, and the exit elevation was chosen to minimize the tunnel length and maximize the slope. The canal invert elevations were chosen to meet the tunnel inverts. Further investigation of these conveyances could result in tunnel and canal elevations that are slightly different. Figure 17 shows the profile of the Stony Gorge to Sites conveyance alternative.

At East Park Reservoir, a single tunnel could convey reservoir water to Sites Reservoir via Funks Creek. Eight alternative tunnel alignments were considered to determine the shortest and steepest location to minimize tunnel length, diameter, and cost (only the four best alignments are shown in Figure 16). Hydraulic analysis, design, and costs were done for the S1, S2, N1, and N2 but not the other four alignments. This was done because the topography under the water's surface is not known for East Park Reservoir, and topography that will allow a tunnel entrance far enough below the water surface likely occurs at the northern (downstream) end of the reservoir rather than the southern end.

The tunnels are between 3 and 10 times as costly per unit length as canals of equal capacity, with base costs of $11 million to $41 million per mile compared to $3.3 million to $4.1 million per mile for canals. Therefore, analysis was done to determine whether increasing tunnel gradients to reduce the excavated diameter and decreasing canal gradients would reduce total costs. Brief analysis showed that there may be some small benefit in designing tunnels with more drop, which may be considered further during the next phase of study.

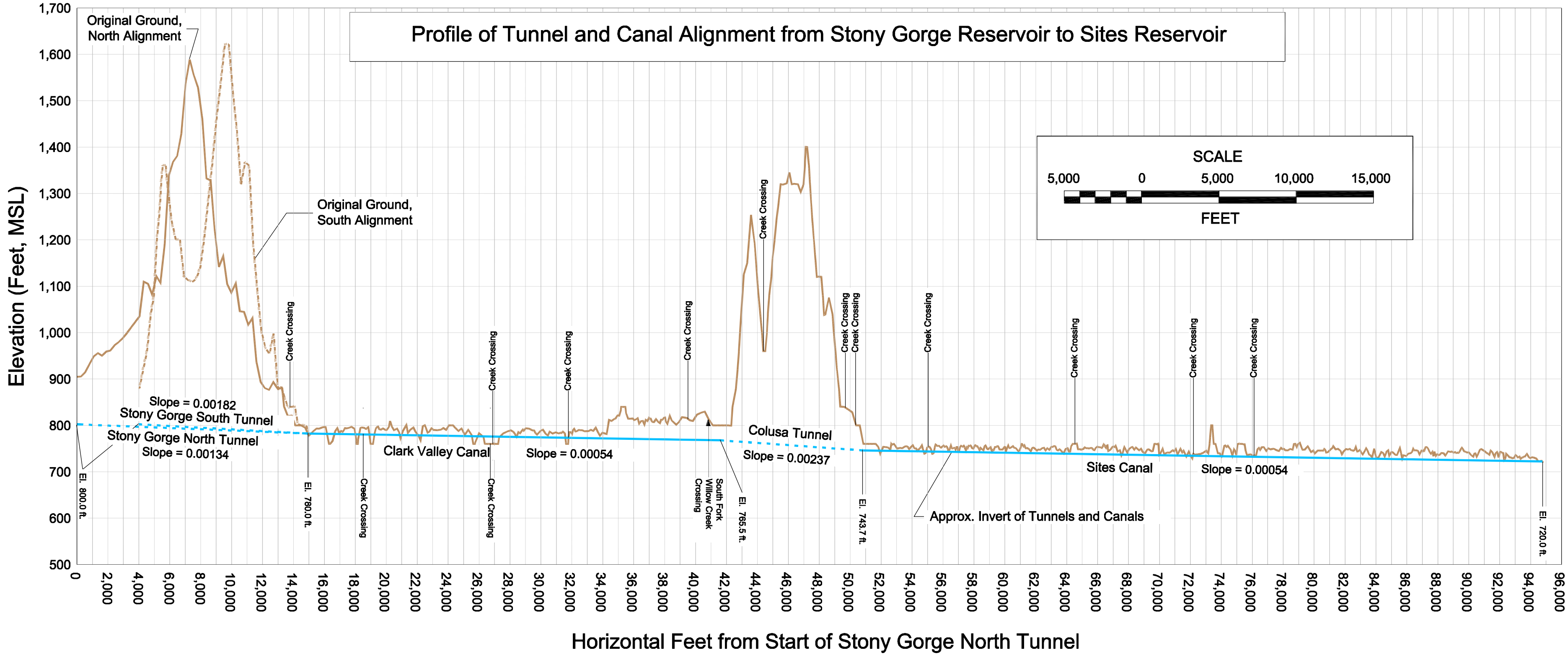


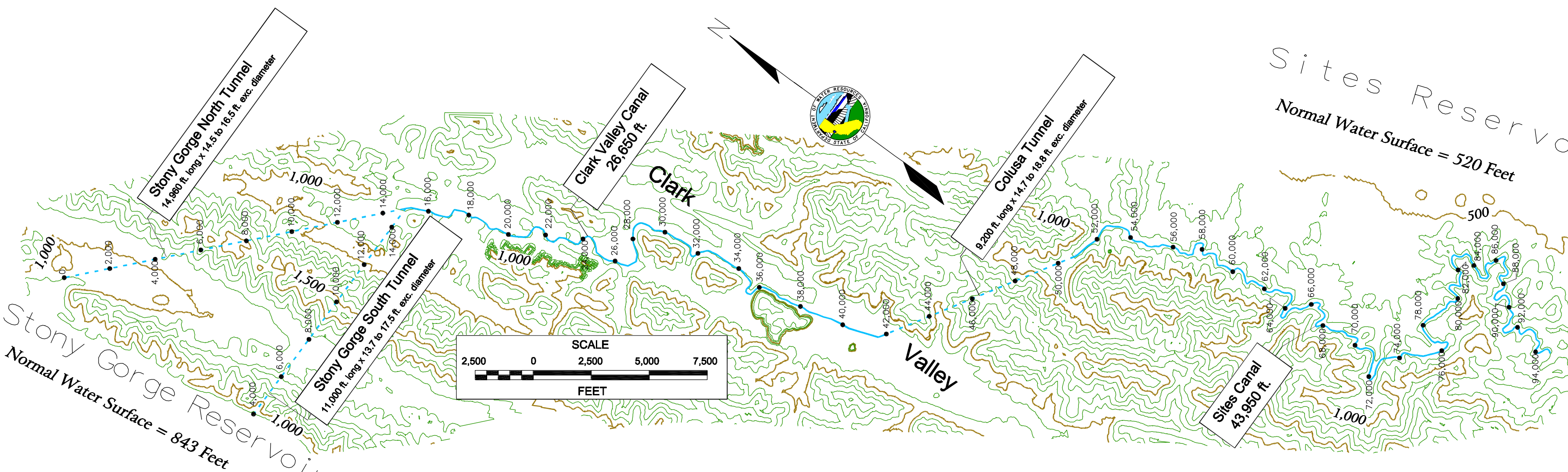
Stony Gorge Reservoir to Sites or Colusa Reservoir
Conveyance Canals and Tunnels



East Park Reservoir to Sites Reservoir Conveyance Alternatives

Figure 16





Plan View of Tunnel and Canal Alignment from Stony Gorge Reservoir to Sites Reservoir

Figure 17

Methodology

Canal costs were projected from 1981 costs in similar, detailed estimates for a proposed Thomes-Newville diversion project. Tunnel costs were derived from the canal costs and the *1957 Bulletin 78, Appendix C (Procedure for Estimating Costs of Tunnel Construction*, in the DWR library), because ND has no recent, detailed costs for tunnel construction. All costs in this memorandum are preliminary and should be revised at a later date by DWR's Division of Engineering. DOE reviewed this report and made comments, some of which are included as recommendations for future work. Designs and costs were based only on surface geology and minimal interpretation.

Further design of project features and cost estimation would require adequate geologic sampling along alignments. Detailed hydrology and cost estimates for tunnels are available from ND.

The information in this report was developed though a preliminary reconnaissance study to determine the potential of Stony Creek as a source of storable inflow to the Sites or Colusa projects. At this point it appears to be a relatively expensive water source and of fairly low priority when compared to other sources currently under investigation. However, most of the detailed technical information is presented in this report to aid future investigators if additional work is judged desirable at a later date.

Technical Data and Cost Summary

The following tables detail the important parameters for each tunnel and canal alternative, as well as, base costs and estimated amounts of storable water for each alternative conveyance. Excavation is the greatest cost item in tunnel construction, and tunnel diameter determines excavation volume. Therefore, tunnel diameters are listed in Table 2. Tunnel support is the next most costly item, so bolt spacing and shotcrete (or cast concrete arch) thicknesses are also listed.

Table 2. Tunnel Alternative Design Features and Costs

Tunnel Alternative (See Figs. 3 & 4)	Flow (cfs)	Length (feet, miles)	Invert Elev. Drop (feet)	Diameter (exc. / finished, feet)	Velocity (feet per second)	Avg. Bolt Spacing (feet)	Avg. Shotcrete Thickness (feet)	Total 1998 Base Cost* ($M)
South Stony Gorge	1,000	11,000 2.1	20	14.4 / 10.6	11.3	3.9	1.9	47
	1,500			16.2 / 12.4	12.4			56
	2,000			17.6 / 13.8	13.4			65
North Stony Gorge	1,000	14,960 2.8	20	15.0 / 11.2	10.2	3.9	1.9	65
	1,500			16.9 / 13.1	11.1			79
	2,000			18.4 / 14.6	11.9			91
Colusa	1,000	9,210 1.7	21.8	16.0 / 11.4	9.8	3.6	2.3	52
	1,500			18.0 / 13.4	10.8			63
	2,000			19.4 / 14.9	11.5			73
East Park S 1	800	18,195 3.4	350	11.0 / 7.1	20.2	3.9	1.9	49
	1,000			11.6 / 7.7	21.5			54 (+ 5)
	1,200			12.1 / 8.2	22.7			58 (+ 10)
East Park N 1	800	20,050 3.8	350	11.1 / 7.2	19.6	3.9	1.7	55
	1,000			11.7 / 7.8	20.9			60 (+ 5)
	1,200			12.3 / 8.4	21.7			64 (+ 10)

* These estimates include cursory costs of tunnel intakes and control facilities. Increments added to East Park tunnel alternatives are approximations of base costs of improvements to the Rainbow Diversion Canal.

Both canals would have 3 feet of freeboard and uniform side slopes for the full length: 2 feet horizontally for each foot vertically up from the base (2:1 H:V). A 4-inch lining of shotcrete would be used to reduce water and friction losses, and to minimize erosion. Costs for blasting or deep ripping were not included, but further study may show the necessity for these methods of excavation in some places. Canal dimensions, hydraulics, and costs are shown in Table 3. Detailed hydrology, design, and cost estimates for canals are available from ND.

Table 3. Canal Alternative Design Features and Costs

Alternative (See Figs. 3 & 4)	Flow (cfs)	Length (feet, miles)	Invert Elev. Drop (feet)	Base Width (feet)	Depth of Water (feet)	Velocity (feet per second)	Total 1998 Base Cost* ($M)
Clark Valley	1,000	26,650 5.1	14.5	15	9	3.4	17
	1,500			15	10.7	3.9	19
	2,000			20	11	4.3	21
Sites	1,000	43,950 8.3	23.7	15	9	3.4	29
	1,500			15	10.7	3.9	31
	2,000			20	11	4.3	34
TOTAL	1,000	70,600 13.4	38.2				46
	1,500						50
	2,000						55

* These estimates include cursory costs of intakes, appurtenances, and other facilities.

Table 4 shows the combined base costs for the entire Stony Gorge Reservoir to Sites Reservoir conveyance tunnels and canals, and base costs for East Park Reservoir to Sites Reservoir tunnels plus rough estimates of base costs of improvements to the Rainbow Diversion Canal. Amounts include cursory costs of appurtenances and facilities.

Table 4. Conveyance Systems Base Costs

Conveyance Alternative (See Figs. 3 & 4)	Flow (cfs)	Length (feet, miles)	Invert Elev. Drop (feet)	Total 1998 Base Cost * ($M)	Approx. Annual Nov.-Mar. Water Delivery (taf)	Approx. Base Cost/Ann. af ($)
South Stony Gorge Tunnel and Canals to Sites	1,000	90,810 17.2	80	145	40	3,600
	1,500			169	55	3,100
	2,000			193	72	2,700
North Stony Gorge Tunnel and Canals to Sites	1,000	94,770 17.9	80	163	40	4,100
	1,500			192	55	3,500
	2,000			219	72	3,000
East Park S 1 (Rainbow Div. = 300 cfs)	800	18,195 3.4	350	49	27	1,800
	1,000			54 (+ 5)	29	2,000
	1,200			58 (+ 10)	30	2,300
East Park N 1 (Rainbow Div. = 300 cfs)	800	20,050 3.8	350	55	27	2,000
	1,000			60 (+ 5)	29	2,200
	1,200			64 (+ 10)	30	2,500

* These estimates include cursory costs of intakes, appurtenances, and other facilities. Increments added to East Park tunnel alternatives are rough estimates of base costs of improvements to the Rainbow Diversion Canal. These improvements would make some additional increment of flow available for diversion through the tunnels.

Table 5 shows the estimated quantities and unit costs as well as the cost estimate for the same tunnel alternative. Table 6 lists estimated quantities, unit costs, and the cost estimate for both the Clark Valley and Sites Canals at the 1,500 cfs size.

Project Geology

Accurate tunnel cost estimates are highly dependent on the level of geologic data. Because only existing cursory geologic information was available for this estimate it must be considered tentative. This estimate may change if drilling data is obtained in the future.

Interpretation of surface geology maps was provided by ND geologists. This information provided the basis for the engineering design and cost estimate. The available surface mapping of the tunnel and canal alignments was interpreted by recent drilling information at the dam sites for Sites and Colusa Reservoirs. There is insufficient bore hole information to use the more modern, detailed rock mass evaluation methods developed during the last 20 years, so the older Terzaghi system of rock classification developed for railroad tunnels was used.

Table 7 shows the analysis of mapping and initial interpretation for the South Stony Gorge and Colusa Tunnel alignments.

Table 5. Cost Estimate for Stony Gorge Reservoir to Sites Reservoir Conveyance, North Stony Gorge Tunnel

Flow (cfs):	**1,500**
Length (ft.):	**14,960**
Starting Invert Elevation (ft):	800
Ending Invert Elevation (ft):	780
Total Fall (ft.):	20
Width & Height, Lined / Unlined:	**13.1 / 16.9**

Item	Terzaghi Rock Classification	Tunnel Length, Feet		Units	Quantity	Unit Cost	Cost
Excavation, Dry	II	3,770		cubic yards	31,227	$199	$6,200,000
	III	2,237		cubic yards	18,531	$171	$3,200,000
	IV	2,237		cubic yards	18,531	$187	$3,500,000
	V	2,237		cubic yards	18,531	$339	$6,300,000
Excavation, Wet	II	1,616		cubic yards	13,383	$537	$7,200,000
	III	959		cubic yards	7,942	$537	$4,300,000
	IV	959		cubic yards	7,942	$537	$4,300,000
	V	959		cubic yards	7,942	$920	$7,300,000
Subtotal, Excavation					124,029		*$42,300,000*
Shotcrete or Cast Concrete Arch		Thickness, Feet	Tunnel Length, Feet				
	II	0.4	5,386	cubic yards	8,900	$380	$3,400,000
	III	0.6	3,196	cubic yards	5,796	$380	$2,200,000
	IV	2.6	3,196	cubic yards	12,230	$380	$4,600,000
	V	4.3	3,196	cubic yards	17,377	$380	$6,600,000
Subtotal, Lining					44,304		*$17,000,000*
Steel Mesh				pounds	2,215,186	$1.10	$2,400,000
Rock Bolt / Anchor		Spacing, Feet	Tunnel Length, Feet				
	II	4.9	5,386	each	20,099	$85	$1,700,000
	III	3.3	3,196	each	17,891	$113	$2,000,000
	IV	3.3	3,196	each	17,891	$170	$3,000,000
	V	3.3	3,196	each	17,891	$255	$4,600,000
Drill and Grout				lump sum			$1,000,000
Portals				lump sum			$4,000,000
Entrance Gate				lump sum			$1,000,000
TOTAL BASE COST							**$79,000,000**

Notes:

1. Estimate does not include contingencies, engineering, regulatory cost, operation and maintenance, capital repayment, energy costs or any other non-base costs.
2. Tunnel costs were estimated by converting Terzaghi Rock Classifications to the system described in the *Norwegian Geotechnical Institute Publication No. 106, Engineering Classification of Rock Masses for the Design of Tunnel Support*.
3. Initial interpretation of surface geological unit mapping and recent bore hole geology shows that no Terzaghi-type, rigid steel support is needed for the alignments considered. This could change with further geology studies.
4. Wet headings were assumed for 30 percent of each tunnel alignment. This appears to be a conservative figure based on North Coast studies, but could change with further geology studies.
5. Sandstone was interpreted as very good rock, Terzaghi RC II, and siltstone or mudstone was interpreted as Terzaghi RC III, IV or V. However, since the proportion of each class within the siltstone or mudstone is not known, it is was assumed that each class had one third of the length within that geologic unit.
6. Lump sum estimates for drilling and grouting, portals and entrance gates are placeholders for later estimates to be made by DOE. Values used are reconnaissance-level estimates.

Table 6. Stony Gorge Reservoir to Sites Reservoir Conveyance

Trapezoidal Concrete-Lined Option

Canal 1 = 26,650 ft. long	Maximum Flow =	1,500 cfs
from 780 ft. to 765.5 ft. elevation	Base Width =	15 ft.
	Side Slopes =	2.0:1 H:V
Canal 2 = 43,950 ft. long	Water Depth =	10.7 ft.
from 743.7 to 720 ft. elevation	Freeboard =	3 ft.

Item	Units	Unit Cost	Quantity	Item Cost
CANAL				
Excavation, common	CY	$3.82	4,190,000	$16,000,000
Embankment (Backfill), common	CY	$1.62	1,975,000	$3,200,000
Embankment (Backfill), compacted	CY	$2.57	1,975,000	$5,100,000
Trimming	SY	$1.25	611,667	$760,000
Concrete, structural	CY	$418	0	$0
Concrete, lining	CY	$200	78,415	$16,000,000
Steel mesh	LB	$1.10	784,150	$900,000
Cement	BBLS	Included in concrete		$0
Gravel drains and bedding	CY	$8.35	78,419	$650,000
Fencing	LF	$22	141,154	$3,100,000
CANAL DEER CROSSINGS				
Deck, 100' wide	LF	$8,350	6@91'=546	$4,600,000
CANAL SMALL TRIBUTARY DRAINAGES				
Culvert, 6' diameter corrugated	LF	$55	720	$40,000
Fittings, 6' dia. culvert	EA	$55	30	$1,700
Excavation / Embankment	CY	$3.00	7,540	$23,000
Concrete, headwalls	CY	$418	28	$12,000
Reinforcing steel	LB	$1.10	4,110	$4,500
S.F. WILLOW CREEK CROSSING				
Dam and Spillway or Bypass		Unknown	Unknown	Unknown
TOTAL BASE COST				**$50,000,000**

Notes:
1. Estimate does not include contingencies, engineering, regulatory cost, operation and maintenance, capital repayment, energy costs or any other non-base costs.

2. Canal costs were projected from 1981 costs in similar, detailed estimates for a proposed Thomes-Newville project.

Table 7. Initial Analysis and Interpretation of Surface Geology Mapping

Tunnel	Map Unit	Substituted Map Unit	Rock Type and Loading	Distance
South Stony Gorge	Modesto Formation, Lower Member	Mudstone	IV 0.35(B + Ht)	1,270’
	Elder Creek terrace, mudstone	Mudstone	IV 0.35(B + Ht)	5,780’
	Elder Creek terrane, Sandstone	Sandstone	II 0.24B	3,960’
Colusa	Modesto Formation, Lower Member	Mudstone	IV 0.35(B + Ht)	400’
	Elder Creek terrace, mudstone	Mudstone	IV 0.35(B + Ht)	7,840’
	Elder Creek terrane, Sandstone	Sandstone	II 0.24B	1,660’

The mudstone in this area can be either “blocky and seamy,” or “crushed.” Therefore, mudstone could be Terzaghi Rock Type III, IV, or V. Since there is no field geology for these alignments, each rock type was assumed to exist for one-third of the mudstone unit. Table 8 shows the distribution of rock types and their lengths for one alignment alternative at each tunnel location. For this reinterpretation, East Park tunnels were assumed to have the same ratio of mudstone to sandstone as the South Stony Gorge Tunnel.

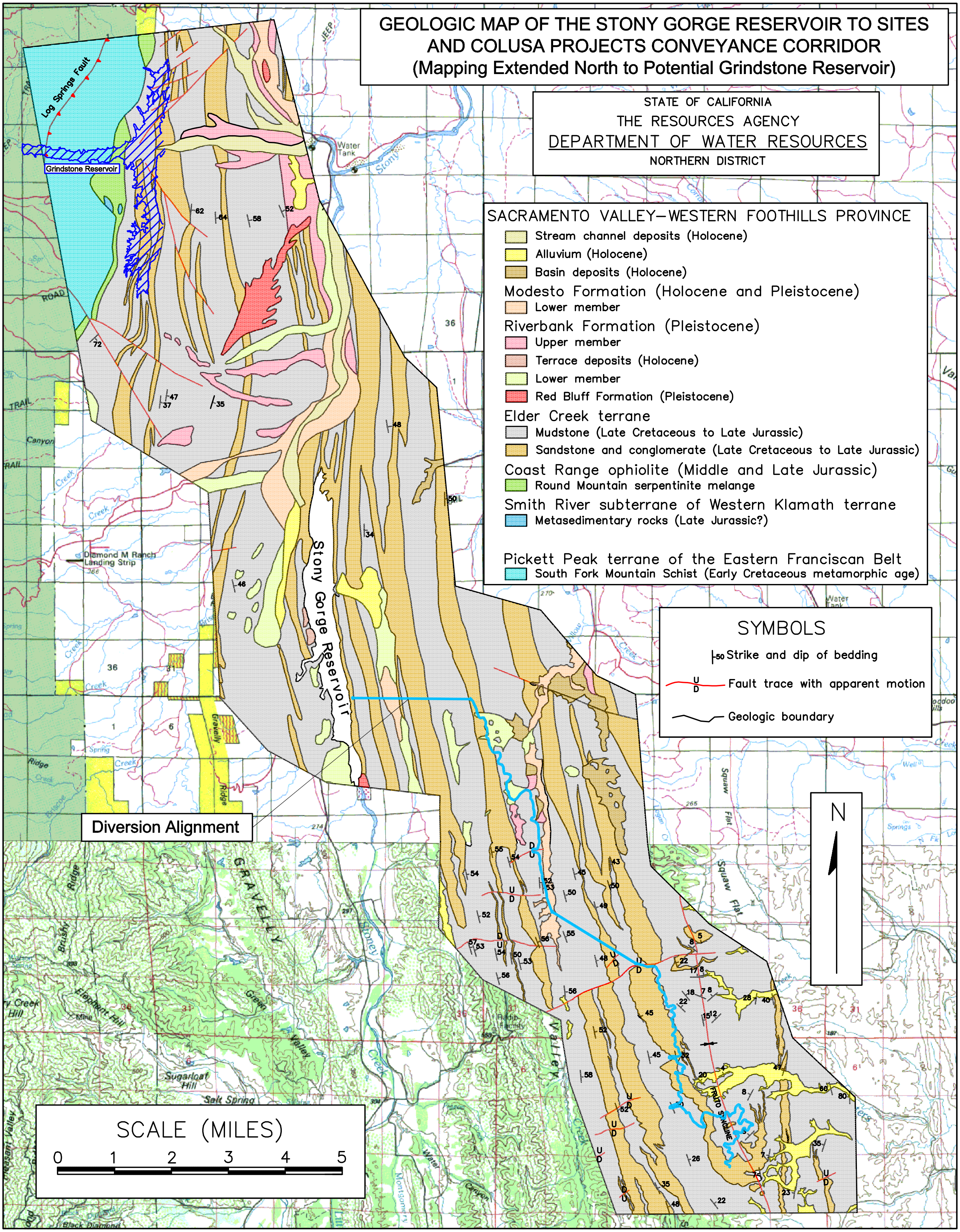
Table 8. Estimation of Rock Type and Water Conditions Along Tunnel Alignments

Tunnel	Terzaghi Rock Type	Distance (Feet)	Distance of 70% Dry Heading (Feet)	Distance of 30% Wet Heading (Feet)
South Stony Gorge	Mudstone:			
	RC III – 0.5 B	2,350	1,645	705
	RC IV – 0.35 (B+Ht)	2,350	1,645	705
	RC V – 1.10 (B+Ht)	2,350	1,645	705
	Sandstone: RC II – 0.35B	3,960	2,772	1,188
Colusa	Mudstone:			
	RC III – 0.5 B	2,747	1,923	824
	RC IV – 0.35 (B+Ht)	2,747	1,923	824
	RC V – 1.10 (B+Ht)	2,747	1,923	824
	Sandstone: RC II – 0.35B	1,660	1,162	498
East Park (assume same Mudstone / Sandstone ratio as Stony Gorge)	Mudstone:			
	RC III – 0.5 B	3,942	2,759	1,183
	RC IV – 0.35 (B+Ht)	3,942	2,759	1,183
	RC V – 1.10 (B+Ht)	3,942	2,759	1,183
	Sandstone: RC II – 0.35B	6,652	4,656	1,996

Details of Canal and Tunnel Design

Tunneling conditions are determined by geology, so geology was examined at a cursory level, although no drilling was done. Surface geology units were mapped from available geologic mapping along the alignment from Grindstone Creek to the proposed Sites Reservoir, as shown on Plate 1. The mudstone would present a variety of tunneling conditions, from fairly competent, blocky and seamy to fairly poor crushed rock. The sandstone would likely consist of

Plate 1



GEOLOGIC MAP OF THE STONY GORGE RESERVOIR TO SITES AND COLUSA PROJECTS CONVEYANCE CORRIDOR
(Mapping Extended North to Potential Grindstone Reservoir)
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
SACRAMENTO VALLEY—WESTERN FOOTHILLS PROVINCE
Stream channel deposits (Holocene)
Alluvium (Holocene)
Basin deposits (Holocene)
Modesto Formation (Holocene and Pleistocene)
Lower member
Riverbank Formation (Pleistocene)
Upper member
Terrace deposits (Holocene)
Lower member
Red Bluff Formation (Pleistocene)
Elder Creek terrane
Mudstone (Late Cretaceous to Late Jurassic)
Sandstone and conglomerate (Late Cretaceous to Late Jurassic)
Coast Range ophiolite (Middle and Late Jurassic)
Round Mountain serpentinite melange
Smith River subterrane of Western Klamath terrane
Metasedimentary rocks (Late Jurassic?)
Pickett Peak terrane of the Eastern Franciscan Belt
South Fork Mountain Schist (Early Cretaceous metamorphic age)
SYMBOLS
50 Strike and dip of bedding
U D Fault trace with apparent motion
Geologic boundary
Log Springs Fault
Grindstone Reservoir
Stony Gorge Reservoir
Diversion Alignment
FRUTO SYNCLINE
Water Tank
Diamond M Ranch Landing Strip
GRAVELLY
Sugarloaf Hill
Salt Spring
Elephant Hill
Squaw Flat
N
SCALE (MILES)
0 1 2 3 4 5

competent, moderately jointed rock. We have no information on water conditions along tunnel alignments, so a value of 30 percent wet headings was assumed.

The geology for the North Stony Gorge Tunnel was assumed to be similar to that of the South Stony Gorge Tunnel because no surface geology mapping was available for this area. The East Park alternative tunnel conditions were similarly assumed to be the same as for the Stony Gorge Tunnels. If any of these tunnels are studied at the feasibility level, bore holes and adits along their alignments will be required.

The geologic mapping and recent bore holes from nearby Golden Gate and Sites Dam sites indicate that rigid steel supports would probably not be needed for the Stony Gorge or Colusa Tunnels. Instead, the tunnels would be excavated in an inverted "U" shape and rock bolted, anchored, and shotcreted as excavation proceeds. This method of support is detailed in *Norwegian Geotechnical Institute Publication No. 106, 1973 (NGI 106)* (available on request). This method of using rock bolts and shotcrete is cheaper than the older railroad tunneling method of rigid supports, and would probably be adequate to bear rock loads for this alternative because the support is applied sooner and allows less deflection (and therefore less final pressure) than rigid steel supports with wood blocks. See Plate 2 for a cross-section view of the tunnels.

Tunnel hydraulics were designed for a circular tunnel instead of the full inverted "U" shape, so tunnels will not run full at the design flow. Therefore, there is some excess capacity at each design flow.

Excavation estimates were based on the necessary tunnel diameter to convey desired flows, plus the necessary thickness of shotcrete or concrete arch. These estimates will change if bore holes are drilled and subsurface geology is sampled, because the required support is dependent on geologic conditions.

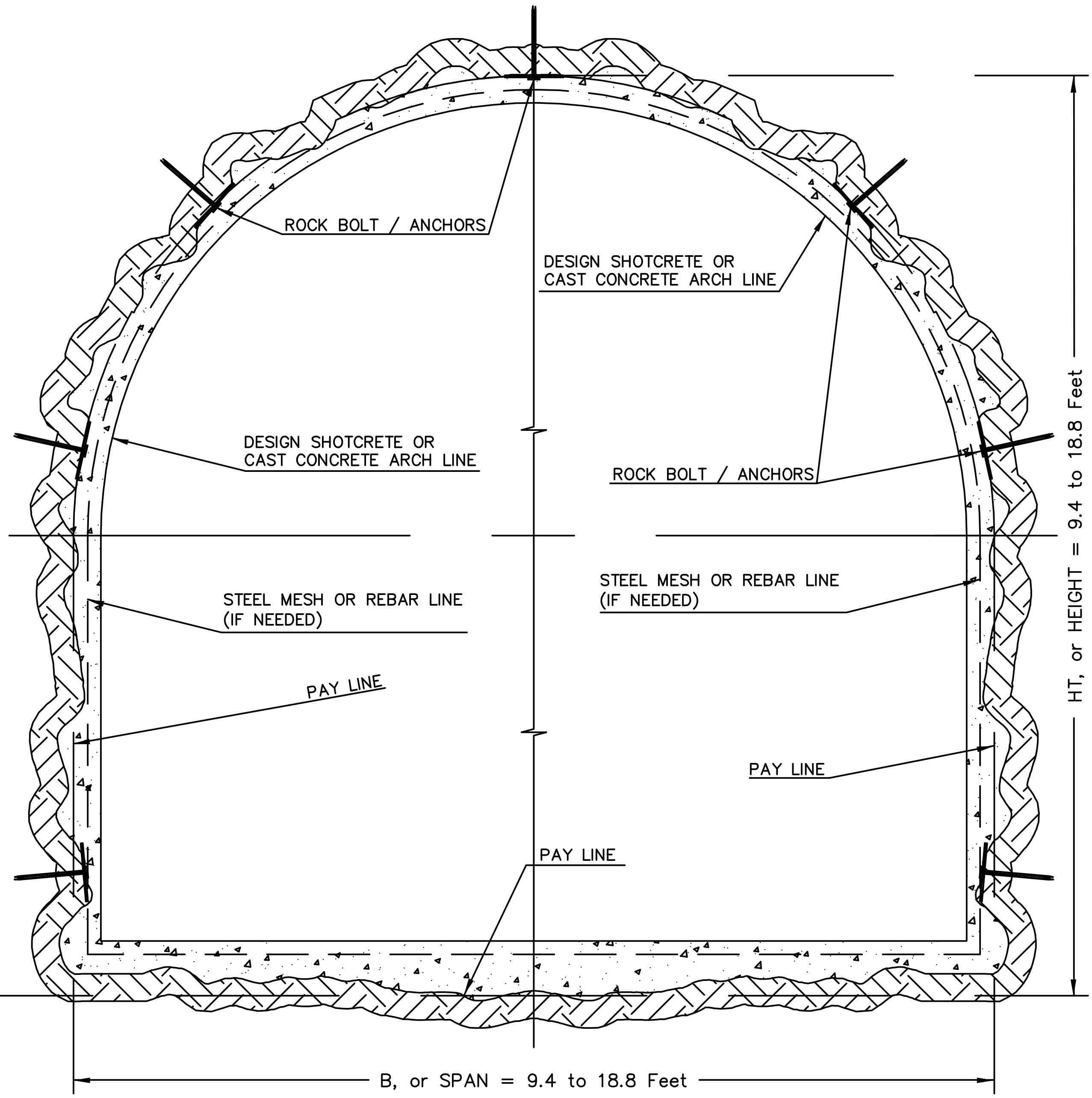
Because no subsurface geologic data were available, the Terzaghi Rock Classifications for the geology was converted to the rock mass quality Q used in *NGI 106*. Terzaghi classifications were used in railroad tunnel designs, such as those in *Feather River and Delta Diversion Projects Bulletin No. 78 Investigation of Alternative Aqueduct Systems to Serve Southern California, Appendix C – Procedure for Estimating Costs of Tunnel Construction, September 1959.* Page 16 of *NGI 106* has a table showing this conversion, and this table was used to derive Q values. All other *NGI 106* factors detailing geology were ignored because detailed geologic information is not available. Table 9 shows the applicable Q values converted from Terzaghi Rock Classifications, as well as the category of support measures.

The canal design was based on information archived in an office document titled *Thomes-Newville Project, Stony Creek Nr. Black Butte to T.C. Canal Conveyance System, 1981* report (Accopress folder, not appended). Since the Clark Valley and Sites Canals are within 25 miles of the diversion canals designed in the Thomes-Newville report, geologic conditions were assumed to be similar.

Canal dimensions are controlled chiefly by the slope, which would be 0.00054 for both the Clark Valley and Sites Canals. Base widths, side slopes, and depths were chosen to minimize cross sectional areas, therefore reducing excavation. Base widths were held to multiples of five feet to reduce the number of excavation calculations needed. Side slopes of 2:1 H:V (2 feet horizontally for

Stony Gorge and East Park Reservoirs to Sites Tunnel Details

SHOTCRETE OR CAST CONCRETE ARCH AND ROCK BOLT / ANCHOR SUPPORT



HYDRAULIC PROPERTIES	
FULL	0.82 DEPTH
Q–$35.3D^{8/3}$ $S^{1/2}$	$35.3D^{8/3}$ $S^{1/2}$
A–$0.8293D^2$	$0.7332D^2$
R–0.2538D	0.3066D
V–$42.6D^{2/3}$ $S^{1/2}$	$48.3D^{2/3}$ $S^{1/2}$
N–0.014	0.014

TYPICAL CAVERN TUNNEL SECTION WITH SHOTCRETE OR CONCRETE CAST ARCH AND ROCK BOLT / ANCHOR SUPPORT every vertical foot) were used for all analyses to provide adequate soil slope stability. See Plate 3 for a typical canal cross- section. Reevaluation of canal sizes in the feasibility stage may reveal base widths, depths, and side slopes that slightly reduce excavation and overall base costs.

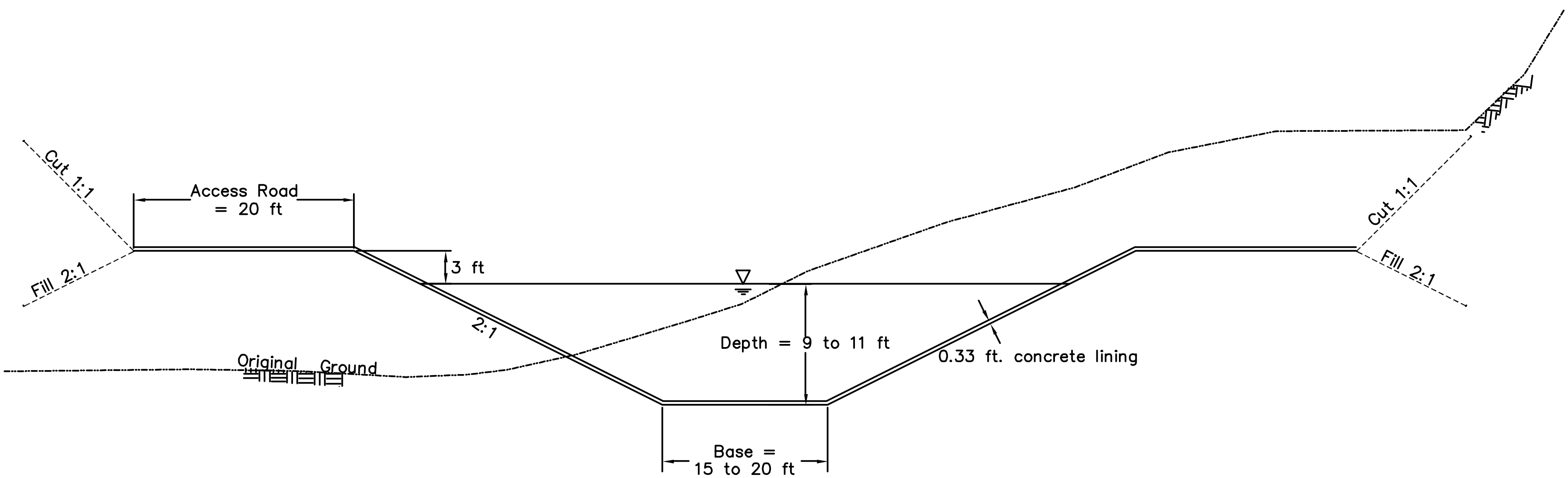
Table 9. Conversion of Terzaghi RC to NGI 106 Q and Support Values

Terzaghi Rock Classification	Range of Possible NGI 106 Q Values (p. 16)	Worst Case Q Value	Range of Possible NGI 106 Support Measures (pp. 22, 36-40)	Worst Case NGI 106 Support Measures
II (Sandstone)	50 – 25	25	13 – 16	16
III (Mudstone)	20 – 10	10	17 – 20	20
IV (Mudstone)	6 – 0.4	0.4	25 – 32	32
V (Mudstone)	0.08 – 0.04	0.04	33 – 35	35

Table 10 is an expansion of Table 9 and provides more detail of support measures determined from pages 22 and 36 to 40 in NGI 106. This detail shows what bolt and/or anchor spacing is needed as well as the thickness of shotcrete or cast concrete arch necessary. Cost estimates for tunnels incorporated the most conservative thicknesses of shotcrete or cast concrete arches, as well as, the smallest bolt spacing. Anchors were not estimated separately, but were assumed to be included in bolt spacing.

Table 11 is an example of tunnel sizing calculations for the North Stony Gorge tunnel at the 1,500 cfs size. This is the methodology used to determine the size of each tunnel alternative.

Stony Gorge Reservoir to Sites Diversion
Channel Cross Section for 1,000 to 2,000 cfs
Concrete Lined Trapezoidal Section



Channel 1

Length = 26626 ft
Elevation from 780 to 765.5 ft
Invert slope = 0.00054
Mannings Roughness n = 0.030
Flow XS area = 300 to 460 sf
Velocity = 3.4 to 4.3 fps
Excavation = 1.5 to 1.7 mcy
Fill = 1.1 to 1.6 mcy

Channel 2

Length = 43951 ft
Elevation from 743.7 to 720 ft
Invert slope = 0.00054
Mannings Roughness n = 0.030
Flow XS area = 300 to 460 sf
Velocity = 3.4 to 4.3 fps
Excavation = 2.6 to 2.9 mcy
Fill = 2.1 to 3.0 mcy

Table 10. Detailed NGI 106 Support Measures Needed for Geologic Conditions

Terzaghi RC	Worst Case Q	Support Category	Type of Support	Notes
II	25	16	S (mr) 10 - 15 cm + B(tg), 1.5 – 2 m {Mesh reinforced shotcrete 10 – 15 cm thick with tensioned bolts spaced 1.5 to 2 meters.}	I, V, VI
III	10	20	S (mr) 10 - 25 cm + B(tg), 1-2 m {Mesh reinforced shotcrete 10 – 25 cm thick with tensioned bolts spaced 1 to 2 meters.}	I, II, III or I, V, VI
IV	0.4	32	CCA (sr) 40-120 cm + B(tg) 1 m {Steel reinforced cast concrete arch 40 to 120 cm thick with tensioned bolts spaced 1 meter.}	IV, VIII, X, XI
V	0.004	35	CCA (sr) 60-200 cm + B(tg) 1 m {Steel reinforced cast concrete arch 60 to 200 cm thick with tensioned bolts spaced 1 meter.}	VIII, X, XI, II

Notes:
I – Tensioned bolts with enlarged bearing plates used, spaced about 1 m, to account for “popping.”
II – Several bolt lengths used, i.e., 3, 5 & 7 m.
IV – Tensioned cable anchors often used to supplement bolt support pressures. Spacing ~ 2 – 4 m.
V – Several bolt lengths – i.e., 6, 8 & 10 m.
VI – Tensioned cable anchors needed, spaced ~ 4 – 6 m.
VIII – Swelling (montmorillonite). Need room for expansion behind support, drainage measures.
X – Squeezing rock, rigid support. [Buer’s geologic work at Golden Gate and Sites Dam locations indicates no squeezing rock. This could change with analysis of adits and bore holes.]
XI – May need bolting after shotcrete if there is a lot of clay, or may need grouted bolts.

Key to support codes:
B = systematic bolting
(tg) = tensioned (expanding shell type for competent rock masses, grouted post-tensioned in very poor quality rock masses; see Note XI)
S = shotcrete
(mr) = mesh reinforced
CCA = cast concrete arch
(sr) = steel reinforced
Bolt spacings are given in meters (m). Shotcrete or cast concrete arch thickness is given in centimeters (cm).

Table 11

Sizing Calculations

Stony Gorge Reservoir to Sites Reservoir Conveyance

North Stony Gorge Tunnel

Elev. = 800 ft. to 780 ft. (20 ft. Fall), Q = 1,500 cfs

Objective: Find the minimum finished diameter tunnel that can convey the required flow, given the slope and length

Q - Flow in cfs	z - Invert elevation in feet	1 - Downstream section
n - Manning's roughness	d - Depth of water in feet	2 - Upstream section
H - Head in feet	P/w - Pressure head in feet	
D - Pipe diameter in feet	h_e - energy losses = $k(V^2/2g)$	
A - Area in sf	K - Energy loss factors	
P_w - Wetted perimeter in feet	S_r - friction slope	
V - Velocity in fps	h_f - friction head loss	
L - Pipe length in feet	R = Hydraulic radius = A/P_w	

Energy equation: $z_2 + d_2 + P_2/w + V_2^2/2g = z_1 + d_1 + P_1/w + V_1^2/2g + h_e$

$Q = (1.486/n)AR^{2/3}S_f^{1/2}$

$hf = (Q^2n^2L)2.21A^2R^{4/3}$ $\quad$ $hf = KfV^2/2g$ $\quad$ $K_f = 2gn^2L/2.21R^{4/3}$

Solve for D

Q(cfs) =	**1,500**	n =	**0.0140**	z_1(ft) =	**780.0**	d_1(ft) =	**11.0**	P_1/w(ft) =	**0.0**
		L(ft) =	**14,960**	z_2(ft) =	**800.0**	d_2(ft) =	**11.0**	P_2/w(ft) =	**0.0**
$K_{entrance}$ =	**0.5**	$K_{transition}$ =	**0.0**	K_{outlet} =	**1.0**				
K_{bend} =	**0.0**	K_{gate} =	**0.0**						

2 - Upstream Section		1 - Downstream Section	
Reservoir?	yes	Reservoir?	no

D_2(ft)	A_2(sf)	V_2(fps)	H_2	D_1(ft)	A_1(sf)	V_1(fps)	K_f	Ksum	H_1	H_2-H_1=0?
8.0	50.27	29.842	831.0	8.0	50.27	29.842	33.91	35.41	1294.5	-463.45
10.0	78.54	19.099	831.0	10.0	78.54	19.099	25.18	26.68	947.8	-116.79
14.0	153.94	9.744	831.0	14.0	153.94	9.744	16.08	17.58	818.4	12.61
12.9	130.70	11.477	831.0	12.9	130.70	11.477	17.93	19.43	832.8	-1.79
13.0	132.73	11.301	831.0	13.0	132.73	11.301	17.75	19.25	831.2	-0.16
13.1	**134.78**	**11.129**	**831.0**	**13.1**	**134.78**	**11.129**	**17.57**	**19.07**	**829.6**	**1.40**

Finding: The minimum finished diameter tunnel that can convey the required flow, given the slope and length, is **13.1 feet**.

Future Work Needed

If the current screening process of potential water sources for the Sites/Colusa project determines that Stony Creek remains a viable alternative, the following feasibility-level work items should be completed:

- Geologic exploration must be done before the quantities and costs of alternatives in this report can be more accurately assessed. Bore holes are needed along the tunnel alignments to map the actual geology at the depths of the tunnels. An evaluation of the blasting required along canal alignments is needed. Adits at the tunnel entrances and exits are necessary to help determine tunneling conditions.
- New cost estimates reflecting data developed by geologic exploration should be done if study of Stony Creek diversions continues.
- Two separate reports are needed: a design and cost estimate of a single size for each alternative, and a report evaluating the comparative cost effectiveness of all alternatives.
- An evaluation of water rights should be done to ensure that the State could store what we assume is potentially divertible water.
- DWR's DOE should update the engineering methodology used in this report, to ensure the most current tunnel design methods are used.

Grindstone Dam and Reservoir Evaluation

The potential to construct a dam and reservoir on Grindstone Creek (see Figure 18) was evaluated at a cursory level. The reservoir could store as much as 110,000 acre-feet of water at an elevation of 1,000 feet mean sea level (see Plate 4). This is a small amount of storage compared to Sites or Newville Reservoirs, which are being evaluated at the 1,800,000 acre-foot and larger sizes.

Table 12 shows the dam volumes for chosen water surface heights. At the maximum reservoir size of 110,000 acre-feet, the total dam volume would be 8.3 million cubic yards. Dams for Sites Reservoir would require less than 30 million cubic yards, and Sites Reservoir can hold as much as 16 times what Grindstone Reservoir could hold. Four times the dam volume per acre-foot of water stored would be required for Grindstone Reservoir, indicating it is far less cost-effective as other alternatives under consideration.

Also, there is the potential for large landslides in the Grindstone Creek watershed above Grindstone Dam. Northern District geologists estimated that up to 1 million cubic yards of rock and soil could slide into a new reservoir, potentially causing large waves that could overtop the dam. Also, normal sediment transport into the watershed is much higher than for the Sites or Newville Reservoirs' watersheds, and a small reservoir would fill at a relatively fast rate. Geologists determined that the dam location is close to a fault, so the final dam section could be larger than already evaluated to account for movement along the fault. For these reasons, this alternative seems relatively undesirable in comparison to other more promising alternatives. Grindstone Reservoir is independent of other, more feasible project components, and may be considered feasible at a later date.

Grindstone Reservoir
Main Reservoir and Optional South Wing

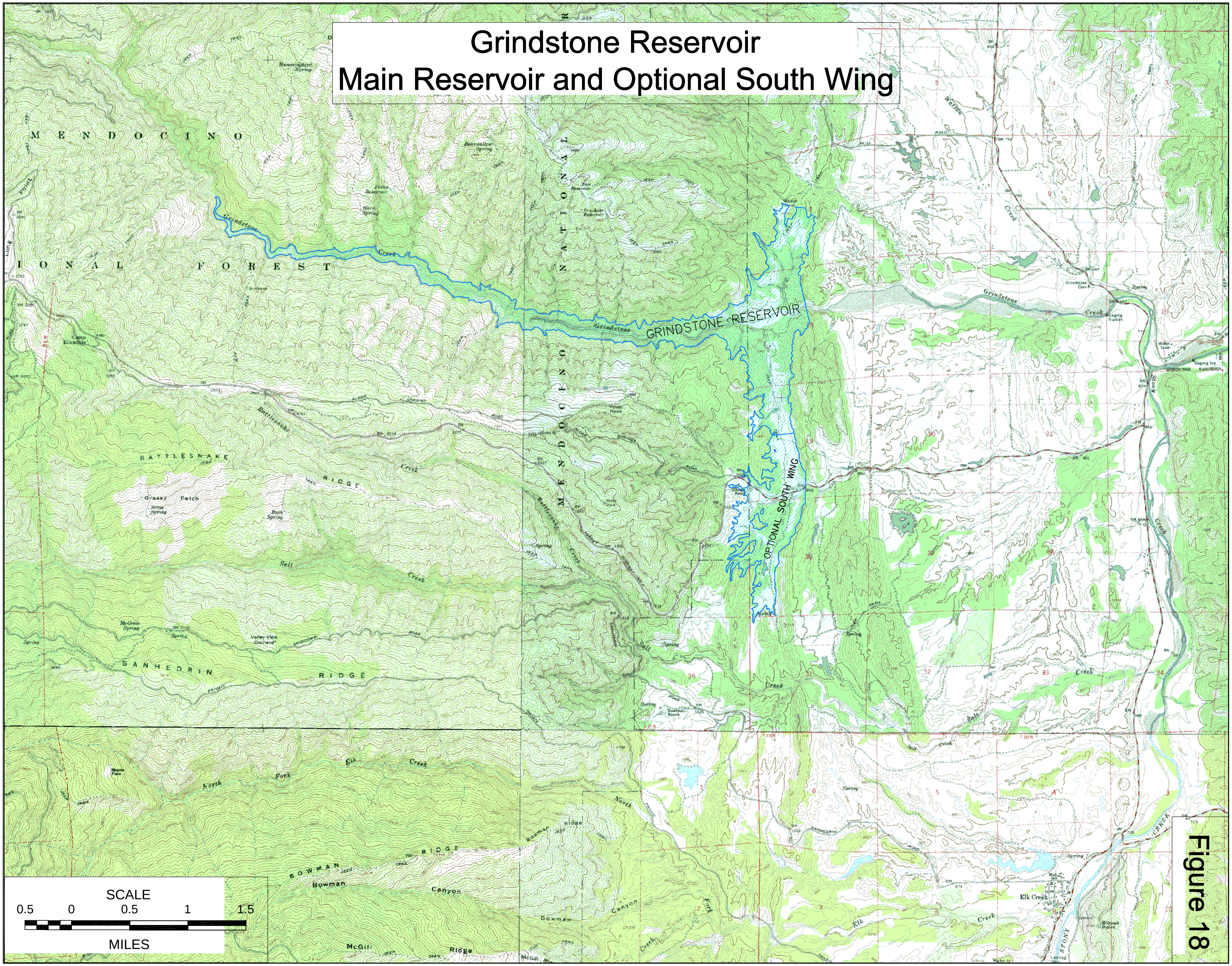


Figure 18

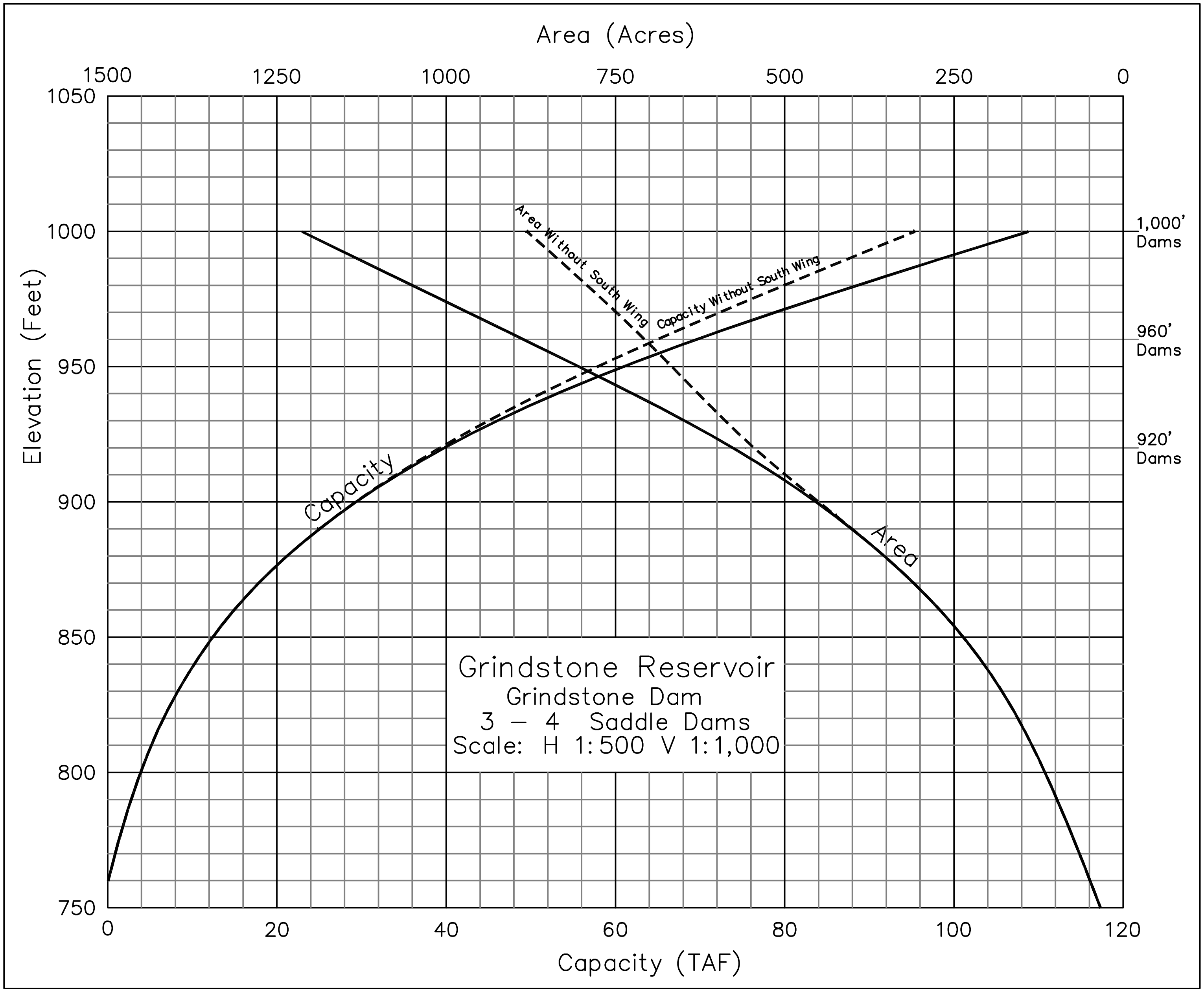

Area (Acres)
1500
1250
1000
750
500
250
0
1050
1000
950
900
850
800
750
Elevation (Feet)
1,000'
Dams
960'
Dams
920'
Dams
Area Without South Wing
Capacity Without South Wing
Capacity
Area
Grindstone Reservoir
Grindstone Dam
3 – 4 Saddle Dams
Scale: H 1:500 V 1:1,000
0
20
40
60
80
100
120
Capacity (TAF)

Plate 4

Table 12. Cursory Grindstone Dam Volumes – January 12, 1997

		Dam Volumes, No Stripping Elevation (Feet)			Stripping Volumes Elevation (Feet)			Total Volumes, Dam and Stripping Elevation (Feet)		
Dam	Type	920	960	1,000	920	960	1,000	920	960	1,000
Main Dam	Earth Fill	1,962,802	3,394,085	5,416,524	477,659	676,131	1,009,373	2,440,461	4,070,216	6,425,897
	Core	329,058	547,689	856,212	72,850	104,003	144,773	401,908	651,691	1,000,985
North Saddle Dam	Earth Fill			52,688			114,784			167,472
	Core			9,013			18,189			27,201
South Saddle Dam	Earth Fill	77,192	438,298	1,307,215	88,017	251,004	616,733	165,209	689,302	1,923,948
	Core	14,474	77,005	215,184	15,905	41,615	81,166	30,379	118,620	296,350
South Cutoff Dam 1	Earth Fill		14,273	196,941		41,165	145,081		55,438	342,022
	Core		2,196	35,656		7,164	26,030		9,360	61,686
Total Grindstone Volume with South Wing:		2,039,995	3,832,383	6,723,739	565,675	927,135	1,626,106	**2,605,670**	**4,759,518**	**8,349,845**
Total Grindstone Volume with South Cut-Off:		1,962,802	3,408,358	5,613,465	477,659	717,296	1,154,454	**2,440,461**	**4,125,654**	**6,767,919**

DRAFT

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